Fluctuations and Invariants in Shallow Water

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LONG-TERM GOALS

The long-term goals are to determine the benefits and limits of using the waveguide invariant approach in underwater acoustic signal and array processing and in quantifying the properties of the ocean environment.

OBJECTIVES

The focus of the work in this program is on analysis of shallow water waveguide propagation. The specific objectives are twofold: 1) to determine the limitations on the invariant approach imposed by mode coupling in shallow water environments where significant temporal variability (e.g., from internal wave activity) and spatial variability (e.g., due to bottom bathymetry changes) occur, and 2) to examine the potential benefits of using the motions of the dislocations in the acoustic pressure field (places where the field amplitude becomes zero and the field phase is undetermined) for inverting for the temporal fluctuations of the water column.

APPROACH

The approach in this program is to use numerical simulations, along with the analysis of existing data, to determine the impact of environmental fluctuations on the waveguide invariant approach. The data sets used in this program came from four experiments, the SWARM 95 experiment (Ref. 1), the 1990 NATIVE 1 experiment (Ref. 2), the 1997 High-Frequency (HF 97) experiment off San Diego (Ref. 3), and the Marine Physical Lab's Adaptive Beach Monitoring program (Ref. 4). Environmental data collected during the SWARM 95 experiment were used to create input models that incorporate various levels of realistic internal wave activity so that the limitations imposed by temporal fluctuations of this type on the waveguide invariant approach could be determined through numerical modeling. Single-tone source tow data collected by vector sensors during the 1990 NATIVE 1 experiment were used to examine the vector intensity properties of the underwater acoustic field and these properties then were related to those expected for pressure and particle velocity field dislocations. Simulations of the data cubes (depth/frequency/time) measured during the HF 97 experiment were performed with increasing levels of complexity incorporated in the input environmental model to help identify the relevant physical phenomena causing the temporal and spatial (in depth) fluctuations. In addition, temporal

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The long-term goals are to determine the benefits and limits of using the waveguide invariant approach in underwater acoustic signal and array processing and in quantifying the properties of the ocean environment.

15. SUBJECT TERMS

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fluctuations in the received level of tones created by a moored underwater source and received by a bottom horizontal hydrophone array in the 1996 Adaptive Beach Monitoring (ABM) experiment were analyzed to search for, and study the motion of, pressure field dislocations. The numerical codes used in the simulations include the RAM parabolic equation (PE) code (Ref. 8), and the adiabatic and conventional coupled normal mode code Kraken (Ref. 9).

WORK COMPLETED

- Interference patterns in acoustic fields have been quantitatively analyzed through the study of the energy flows (reactive intensity) required to support their existence. As part of this effort, the energetics of sound field dislocations were derived. Results have been used to analyze source tow data collected by freely drifting acoustic vector sensors in the NATIVE 1 experiment to determine the existence and prevalence of dislocations. Results were documented in Publ. 1.

- The SWARM 95 environmental reconstruction for one time period has been decomposed into a range-averaged component and a fluctuation component. A set of environments containing varying degrees of the fluctuation component have been created for use in numerical modeling studies. Extensive numerical modeling using the Kraken normal mode, both adiabatic and coupled mode, and RAM PE codes has been performed with these environments. The impact of water column fluctuations and range-varying bathymetry on received acoustic field quantities in addition to acoustic pressure have been examined (Publ. 1).

- The vertical array data collected during the source transmissions (LFM sweeps over 2.5-3.5 kHz and 5.0-7.0 kHz) in the HF 97 experiment have been processed, plotted, and analyzed in several different ways. Broadband numerical modeling with RAM PE and the normal mode code Kraken has been conducted for a variety of environmental input models and for various amounts of additive numerically-modeled ocean noise. The time-dependent sound speed profiles for this numerical modeling effort were derived from thermistor string time series recorded during HF 97, extended to full ocean depth using a linear internal wave propagation code. Results will be submitted for publication in the near future (Ref. 11). (See also Refs. 6 and 7).

- An international workshop titled "Ocean Acoustic Interference Phenomena and Signal Processing Workshop" was organized and conducted in San Francisco, California from 1-3 May, 2001. The 12 papers written by the participants presently are going through final editing, and the proceedings from the workshop will be published by the American Institute of Physics in 2002.

RESULTS

- The existence of interference patterns in acoustic fields is dependent upon a type of acoustic energy flow, the reactive intensity. Analytical expressions for the behavior of these patterns can be obtained by minimizing the reactive component of energy flow through a stationary phase approach, analogous to the method of minimizing active intensity in deriving the concept of group velocity (Publ. 1).

- When the adiabatic approximation is valid, the effect of introducing water column fluctuations on the interference structures in acoustic fields is to cause them to shift in frequency and range in a predictable way while remaining fixed in depth. These shifts occur for the pattern as a whole, so that the holes in the field ("dislocations") need not be the features of the acoustic field that are tracked in oceanographic studies. Significant mode coupling causes the patterns to move and change in complicated ways (Publ. 1).

- Interference patterns can be destroyed in the presence of mode coupling and are particularly unstable where the dynamic range of the pattern (peak-to-trough ratio) is small. The dynamic range of the interference patterns - and therefore their sensitivity to mode coupling - is depth dependent and dependent upon which property of the acoustic field, acoustic energy density or acoustic energy flux, is measured (Publ. 1).

- During the NATIVE 1 source tow, the active intensity typically is dominated by the radial component directed away from the source, representing net flux down the waveguide, and the reactive intensity is oriented mostly in the vertical direction since the spatial variability of the field is greatest in this direction. However, deviations in these typical behaviors occur at a few ranges and depths that are consistent with the behavior expected near dislocations. In particular, the radial component of the active intensity can point towards the source, indicating net flux of acoustic energy in that direction (Publ. 1).

- Using actual underwater acoustic data collected by NRL's vertical line array in SWARM 95, regions in the data cubes (depth, frequency, time) for the 100-Hz-wide transmissions centered at 400 Hz where sound field minima are concentrated vary considerably from one transmission to the next. However, histograms of the distribution of minima in subunits of the data cubes are quantitatively similar.

- The characteristic temporal scales of the fluctuations in the underwater acoustic data from the HF 97 experiment do not appear to vary as a function of depth. However, they clearly are a function of vertical wave number. At steeper angles of arrival, where the acoustic field energy interacts with the ocean surface, the temporal scales are several seconds, whereas those for low angles of arrival are a few minutes. Numerical modeling results, using the thermistor-string-data derived time-dependent sound speed profiles, show fluctuation characteristics that are quantitatively similar (by various statistical tests) to those observed in the actual acoustic data at low angles of arrival (Ref. 11).

- Pressure field dislocations tentatively have been identified in the ABM 96 data, and their motion as a function of time across the horizontal aperture of the bottom hydrophone line array over selected short time periods (5 min) has been observed. Some of the variability is correlated with changes in the waveguide thickness due to incoming swell (as measured by an oceanography sensor package located near the moored source). However, other factors clearly contribute to the dislocation motion.

IMPACT/APPLICATIONS

Waveguide invariant techniques provide a powerful, alternative way of examining sound propagation in a multipath environment. Along with concepts from the energetics of acoustic fields, they can be applied to the study of the impact of water column fluctuations on received acoustic fields, and the use of these effects for determining the water column fluctuation properties (e.g., Ref. 12).

TRANSITIONS

The results from this basic science project, both the analytical approaches and the numerical models that have been developed, are being used in more applied programs - re Related Projects #1 and #2.

RELATED PROJECTS

1. "Waveguide Invariants and Space-Frequency-Time Signal Processing," W. A. Kuperman and G. L. D'Spain - algorithms and techniques developed in this program are directly applicable to the analysis of the broadband data.

2. "Passive Synthetic Aperture Sonar (PasSAS)," MPL's FY00 ARL project - the effects of medium fluctuations on normal mode coupling are a critical issue in both programs.

3. The SWARM Program - environmental and underwater acoustic data from the 1995 SWARM experiment, provided to us by Bruce Pasewark, Steve Wolf, Altan Turgut, and Marshall Orr at NRL, and by Jim Lynch at WHOI, have been used to examine mode coupling effects on the waveguide invariant approach.

4. "The Adaptive Beach Monitoring Program", MPL's integrated 6.1/6.2 program - provides data from a fixed/fixed experiment geometry in very shallow water to examine motion of acoustic field minima and dislocations across the aperture of a horizontal array.

REFERENCES

1. J. R. Apel, M. Badiey, C. S. Chiu, S. Finette, R. Headrick, J. Kemp, J. F. Lynch, A. Newhall, M. H. Orr, B. H. Pasewark, D. Tielbuerger, A. Turgut, K. von der Heydt, and S. Wolf, "An overview of the 1995 SWARM shallow-water internal wave acoustic scattering experiment", IEEE. J. Ocean. Engin., 22(3), 465-500 (1997).

2. G. L. D'Spain, W. S. Hodgkiss, G. L. Edmonds, and M. Darling, "Freely drifting Swallow float array: August 1990 NATIVE 1 experiment (first deployment)," Marine Physical Laboratory, Scripps Institution of Oceanography: San Diego, California, MPL TM-426 (1991).

3. N. M. Carbone and W. S. Hodgkiss, "Effects of tidally driven temperature fluctuations on shallow water acoustic communications at 18 kHz," IEEE J. Ocean. Eng. 25, 84-94 (2000).

4. G. L. D'Spain, L. P. Berger, K. M. McArthur, W. S. Hodgkiss, M. J. Ritter, and W. A. Kuperman, "Twinkling of low-frequency tones from a moored source transmitting through and away from the surf zone," J. Acoust. Soc. Am., Vol. 101(5), 3031 (1997).

5. G. L. D'Spain, D. P. Williams, and W. A. Kuperman, "Energetics of dislocations in ocean acoustic fields," J. Acoust. Soc. Am. 108 (5), 2543 (2000).

6. D. P. Williams, G. L. D'Spain, W. S. Hodgkiss, and W. A. Kuperman, "Imaging acoustic fluctuations in shallow water using dislocation theory," J. Acoust. Soc. Am. 108 (5), 2542 (2000).

7. D. P. Williams, G. L. D'Spain, and W. A. Kuperman, "Internal wave effects on ocean acoustic propagation in shallow water," J. Acoust. Soc. Am. 109 (5), 2421 (2001).

8. M. D. Collins, "User's Guide for RAM Versions 1.0 and 1.0p," Naval Research Laboratory, Washington, DC. (1995).

9. M. B. Porter, "The Kraken normal mode program", user's manual, SACLANT Undersea Research Centre, La Spezia, Italy (1995).

10. G. L. D'Spain and W. A. Kuperman, "Application of waveguide invariants to analysis of spectrograms from shallow water environments that vary in range and azimuth", J. Acoust. Soc. Am. 106 (5), 2454-2468 (1999).

11. D. P. Williams, G. L. D'Spain, and W. A. Kuperman, "Internal wave effects on ocean acoustic propagation in shallow water," in prep. (2001).

12. G. L. D'Spain, P. A. Lepper, J. A. Smith, E. J. Terrill, L. P. Berger, and W. A. Kuperman, "Interference patterns in shallow water acoustic fields," Proc. 17th Int'l Congress on Acoustics, 2 pgs. (2001).

PUBLICATIONS

1. G. L. D'Spain, D. P. Williams, G. Rovner, W. A. Kuperman, and the SWARM 95 Team, "Energy flow in interference fields," in Ocean Acoustic Interference Phenomena and Signal Processing, ed. W. A. Kuperman and G. L. D'Spain, AIP Press, 24 pgs., (2002).